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BIOLOGICAL AEROSOL TRIGGER (BAT) DESIGN

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In recent history, man-made and natural events have shown us the ever-present need for systems to monitor the troprosphere for contaminates. These contaminants may take either a chemical or biological form, which determines the methods we use to monitor them. Monitoring the troposphere for biological contaminants is of particular interest to the U.S. Army Edgewood Chemical Biological Center. Whether man-made or natural, contaminants of a biological origin share a similar constitution; typically the aromatic amino acids tryptophan, phenylalanine, and tyrosine. All of these proteinaceous compounds autofluoresce when exposed to ultraviolet radiation, and this establishes the basis of the laser-induced fluorescence (LIF) technique used to detect biological contaminants. This technique can be employed in either point or remote detection schemes and is a valuable tool for discriminating proteinaceous from nonproteinaceous aerosols. This report describes a breadboard point sensor that was designed and fabricated to detect proteinaceous aerosols. Previous point sensor designs relied on convoluted flow paths to concentrate the aerosols into a solution. Other systems required precise beam alignment to evenly distribute the energy irradiating the detector elements. Our objective was to build a simple system, where beam alignment is not critical and the flow is straight and laminar.

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PREFACE

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BIOLOGICAL AEROSOL TRIGGER (BAT) DESIGN

1. BACKGROUND

With the advent of weapons of mass destruction there has been a continuing struggle to maintain technology to render these weapons unusable. The ongoing events in Southwest Asia only magnify the need to increase our technical capabilities to meet the threat.

Our team primarily performs exploratory development of standoff detection concepts for chemical and biological agent detection. Some of these systems have the capability to detect generated aerosols up to 100 km away. These systems are, however, large and consume more than a few kilowatts of power. For a small mobile force, we require something smaller. To meet this requirement, we have used our knowledge of standoff concepts to design point detectors based on similar optical technologies.

2. INTRODUCTION

The U.S. Army Edgewood Research, Development and Engineering Center (ERDEC)[§] has funded work on three point sensors based on laser induced fluorescence of biological materials. The first design, developed by Lincoln Labs (Concord, MA), is based on an imaging scheme. The volume where the laser beams interact with the biological aerosol is imaged onto two detectors with two large concave mirrors. This is a good design and has proven to work well. However, it is very sensitive to misalignment and internal component contamination. The other design takes a completely different approach and is being developed by Science and Technology Corporation (Hampton, VA) in conjunction with ERDEC. This system is designed to take advantage of natural wind flow through the instrument; there are no mechanical pumps. The draw back to this design is the open optical system. The scheme allows solar radiation to enter the system thus increasing system noise. Optical baffling can decrease the signal noise but may disrupt airflow through the system.

This report lays out the path followed to mitigate the alignment and contamination problems of the first scheme and the noise problems of the second scheme. The report includes only the opto-mechanical design of the Biological Aerosol Trigger (BAT). Another report is being prepared detailing the test data analysis and results.

[§] Now known as the U.S. Army Edgewood Chemical Biological Center

3. DESIGN

Three problems that needed solving in this biological aerosol trigger (BAT) were the alignment problem, the flow path problem, and the internal contamination problem. We performed several iterations before arriving at a design that would fulfill development requirements. A schematic of the design problem is shown in Figure 1. As you can see, the aerosol flows into the apparatus and must interface with the laser beam allowing laser scatter and fluorescence to be detected. The flow must be confined to eliminate contamination of any optics and detectors in the system. The obvious way to allow the laser beam to interface with the aerosol is to use a window; but how do you keep the windows clean? Once the laser beam and aerosol flow interface design was laid out, we needed to solve the alignment problem and keep internal components clean.

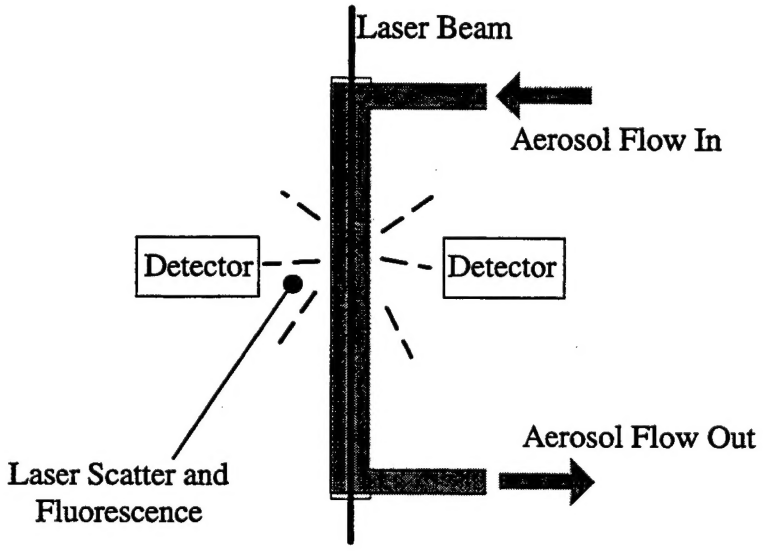

Figure 1. Design Schematic

4. OPTICAL/AEROSOL INTERFACE PROBLEM

It seemed that keeping the optics clean would be the most difficult problem. A considerable amount of time was spent on this portion of the design phase. The design we came up with for the aerosol/optical interface is shown in Figure 2. The laser beam enters through a window into the upper chamber and proceeds through the axis of the chamber. Clean air enters the upper chamber and pushes through a small hole in the cone shaped nozzle. This action prohibits aerosols from backing into the upper chamber and fouling the entrance window. The aerosol enters from the sides of the lower chamber and proceeds along the axis of the chamber with the laser beam. Together the laser beam and aerosol enter the optical chamber.

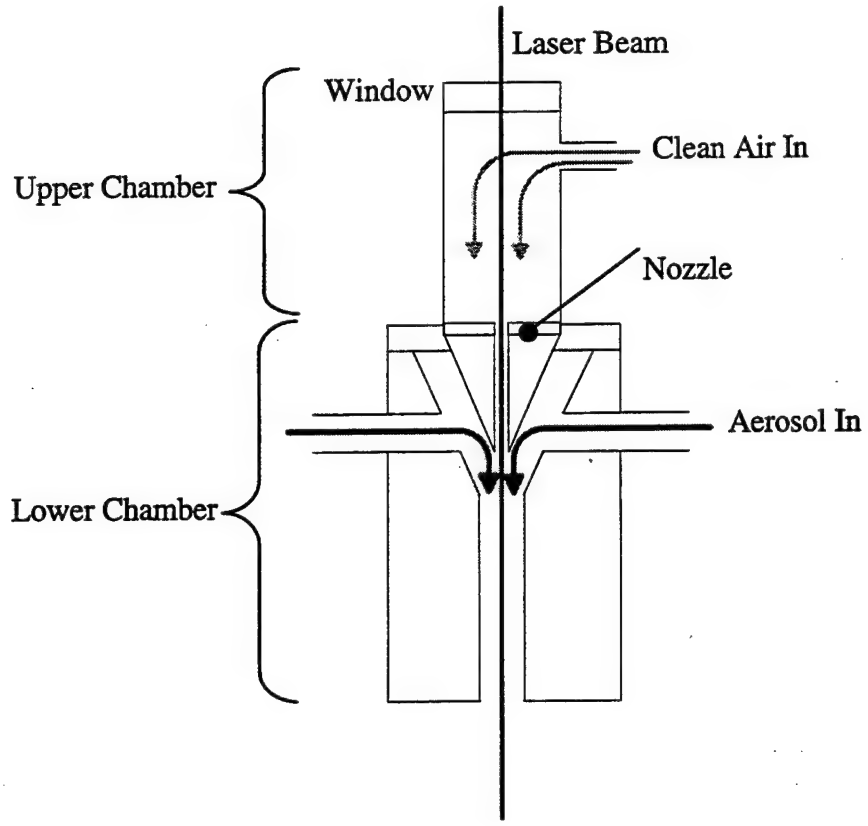

Figure 2. Optical/Aerosol Interface Chamber

5. ALIGNMENT PROBLEM

As stated, Lincoln Laboratory also designed a point sensor based on the technique of laser-induced fluorescence. In their initial design, the detectors were mounted so that they were directly illuminated by the laser scatter and resulting fluorescence (a design that looked very similar to Figure 1). After several field trials, Lincoln Laboratory determined that this was a bad arrangement. The detectors were very sensitive to the beam location. Because the detection algorithm was based on a ratio of the detector signals, this could mean a missed detection or a false alarm. Lincoln Laboratory solved the problem by optically coupling the scatter (and fluorescence) onto both detectors from the same image plane. However, this solution required very precise beam alignment within the image plane to maintain sensitivity

We wanted an optical coupling scheme that was tolerant of beam location and required a minimum of optical interface design. The answer to the problem was the integrating sphere. These optical instruments have been around for years and are used primarily for optical calibration of detectors and sources. The inner surface of an integrating sphere is a Lambertian reflector. Radiation falling on the surface is diffusely reflected such that the radiance is not a function of angle and is given by

$$L_s = \rho I/\pi \,, \tag{1}$$

where ρ is the surface reflectance and I is the irradiance on the surface.[1]

The unique trait of an integrating sphere is that the irradiance at the sphere surface is uniform and independent of the location of the source.[2] If we place a detector on the sphere then the radiance on the detector is

$$d\phi = \frac{\rho}{1-\rho}\frac{\phi_s}{4\pi R^2}dA \,, \tag{2}$$

where ϕ_s is the source radiance, R is the sphere radius and dA is the area of the detector.[3] Equation 2 must be modified slightly to take into account the entrance and exit ports in the sphere and the modified equation is

$$d\phi = \frac{\rho}{(1-\rho)(1-f)}\frac{\phi_s}{4\pi R^2}dA \,, \tag{3}$$

where

$$f = \frac{A_i + A_e}{4\pi R^2} \,, \tag{4}$$

and A_i and A_e are the areas of the entrance and exit ports respectively.[4] As you can see from equation 3, the radiance at the detector is not a function of source location or proximity. The optical efficiency of the sphere is only a few percent, but with a high power laser and a large aerosol sampling volume, we hoped to allay the low optical efficiency. The only other restriction for use of the integrating sphere is that the source cannot directly illuminate the detector and all ports must be small compared to the surface of the sphere.

6. CONTAMINATION PROBLEM

There is now a method to couple the laser beam and the aerosol flow and a method to sample radiation that is invariant to location or distance. Now all we have to do is keep the whole thing from becoming contaminated. The simplest method would be to limit the flow to an axis of the sphere through a tube. The tube must have certain parameters, of which the most important is transparency at the scatter and fluorescence wavelengths. Initially, we designed the apparatus with a fused silica tube. Fused silica is transparent from 200 nm into the near infrared, however these tubes are not readily

available and the cost to have a few made was prohibitive. A Pyrex® tube was selected, which could be procured from several sources, in any size needed, and at a very modest price. The laser wavelength used for the laser induced fluorescence technique is 266 nm (the fourth harmonic of a Neodimium:Yittrium Aluminum Garnet (Nd:YAG) laser). Based on preliminary measurements made with a bread boarded integrating sphere and detector, more than enough laser radiation and fluorescence was transmitted through the Pyrex® tube.

The final problem was to keep the tube clean. Maintaining a laminar flow through the tube keeps contamination to a minimum and a small mechanical design change allows easy tube replacement when it becomes contaminated. The final design for the optical chamber is shown below in Figure 3.

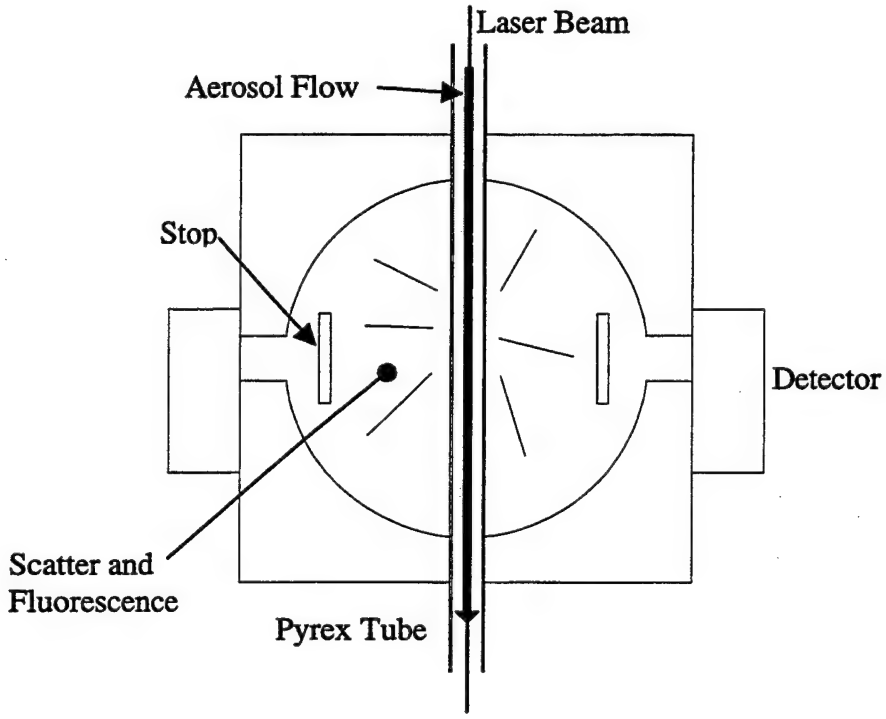

Figure 3. Optical Chamber

Once the laser beam and aerosol exited the optical chamber, another optical/aerosol interface chamber (of the same design described above) was used to remove the aerosol from the system and dump the laser beam to prevent backscatter into the optical chamber. The exit chamber is shown in Figure 4.

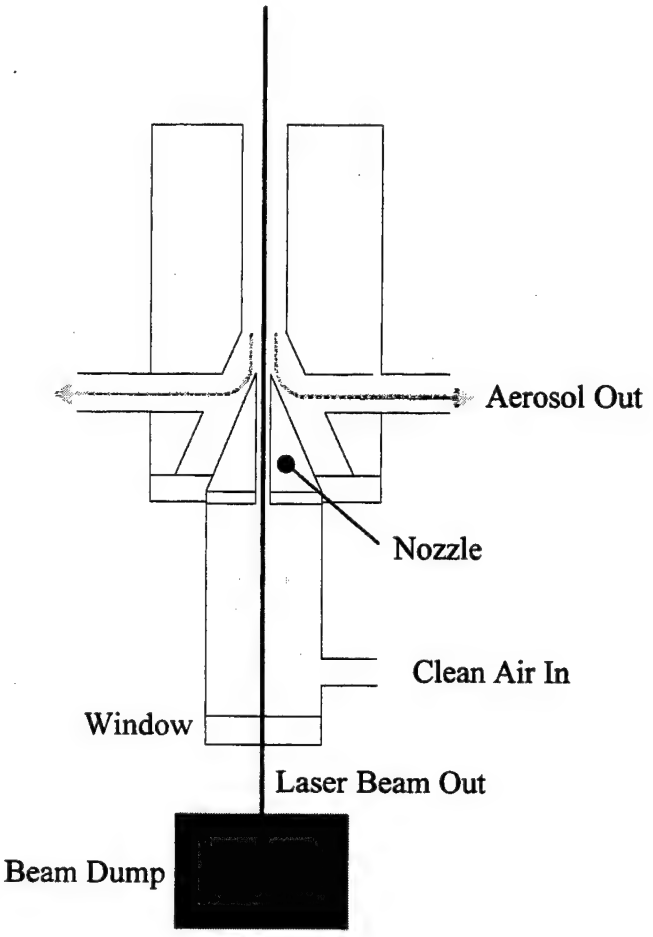

Figure 4. Aerosol/Laser Beam Exit

7. TESTING THE SYSTEM

Initial system tests seem to indicate that the BAT breadboard was working, as it should. There was only time for two days of very preliminary testing before the system was taken to Dugway Proving Ground (DPG), UT, for the Joint Field Trial (JFT) scheduled in September and October of 1997. The tests were run using kaolin dusts and egg albumin. As expected, the data indicated a strong fluorescence for the egg albumin and negligible fluorescence with kaolin dust. We must point out here that these trials were executed using a fairly high concentration of dry aerosols. After these trials, the instrument was disassembled for cleaning. While cleaning the instrument, we noticed an accumulation of dusts in the lower part of the aerosol/optical interface chamber where the flow funnels into the Pyrex® tube. This was obviously due to some turbulence where the flow is constricted. There was no time to change the design prior to JFT4, so we re-assembled the BAT and packed it for shipment to DPG. A complete layout of the BAT, as tested, is displayed in Figure 5. Data acquisition and power equipment was mounted in rack beneath the system.

1. Aerosol Intake
2. Laser Power Monitor
3. Turning Mirror
4. HEPA Filter
5. Laser
6. Vacuum Pump Connect
7. Beam Dump

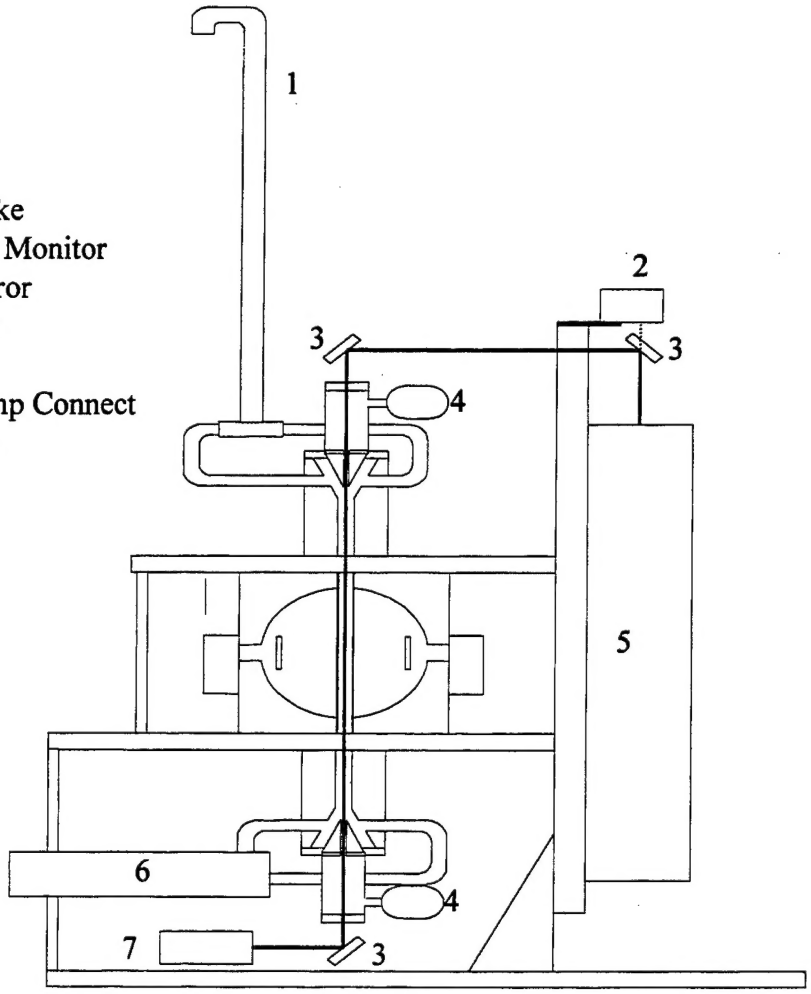

Figure 5. BAT, Complete Layout

The trials in DPG were drastically different from the preliminary trials we conducted at ERDEC. The objective of the trials was to test the sensors against fairly low concentrations of biological simulants. In addition, these simulants were disseminated wet, which may have resulted in a large portion of the aerosols sticking to the inside of the instrument. The BAT breadboard did not fair particularly well during these tests. The system triggered only once during the trials and then against a fairly large concentration (in excess of 200 particles/L). Upon returning to ERDEC, the raw data was re-evaluated after changing some algorithm parameters and eliminating some of the signal noise (which was unusually high). We managed to see a few more triggers but the sensitivity was still less than we had hoped.

8. CONCLUSIONS AND REDESIGN

The less than stellar performance of the Biological Aerosol Trigger (BAT) breadboard may be attributed to two problems. We concluded, after some re-examination of the mechanical design, the flow through the system needs to be simpler. In addition, we need to examine the causes of the signal noise level in the system and evaluate other detectors and acquisition systems. Not all of the news is bad. We learned a lot from this disappointment and we have redesigned the BAT to eliminate the flow problem (see Figure 6). This straight-line flow should prevent particle loses in the system due to accumulation at bends in the flow path.

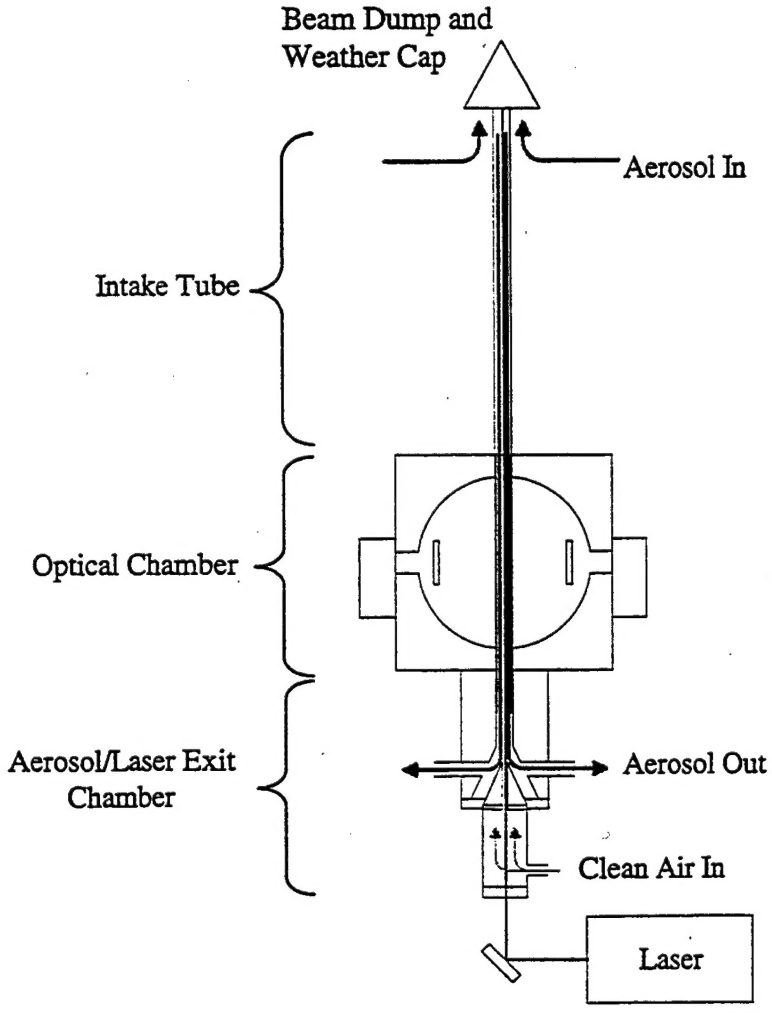

Figure 6. New Design for the BAT

The one part of the system that did live up to design specifications was that portion of the aerosol/optical interface chamber designed to keep the optics clean. The laser windows on the top and bottom were free of dust even after 4 weeks of trials in the Utah desert.

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